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# PROSPECTS OF EXPERIMENTAL DETERMINATION OF BALLISTIC FIRING ELEMENTS

*The analysis of accuracy requirements for ballistic firing elements is given. The necessity of determination of the pressure of powder gases in the bore by measuring of the instantaneous velocity of the throwing element is justified, two methods for solving of this problem are considered. The optical differential Doppler method as a basis for measuring of the velocity of the throwing element is suggested to apply. The main scientific tasks for creation of a measuring device are justified.*
*K e y w o r d s*: *small arms, ballistic firing elements, Doppler's measuring device*

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# ПЕРСПЕКТИВИ ЕКСПЕРИМЕНТАЛЬНОГО ВИЗНАЧЕННЯ БАЛІСТИЧНИХ ЕЛЕМЕНТІВ ПОСТРІЛУ

*Проведено аналіз вимог до точності визначення балістичних елементів пострілу. Обґрунтована доцільність визначення тиску порохових газів у каналі ствола шляхом вимірювання миттєвих значень швидкості руху метального елемента, розглянуто два методи розв'язування такої задачі. Запропоновано в основу засобу вимірювання швидкості руху метального елемента покласти оптичний диференціальний доплеровський метод. Обґрунтовано основні наукові задачі, розв'язування яких має передувати створенню такого засобу вимірювання.*
*К л ю ч о в і  с л о в а: стрілецька зброя, балістичні елементи пострілу, доплеровський вимірювач швидкості.*

**Statement of the problem.** The research of possibilities and ways to improve of existing and creating new weapons, to improve its tactical and performance characteristics are the priority tasks that are set before the scientists, who are working in the interests of the Interior Troops of MIA of Ukraine.

The scientific investigations in this area may be directed to the development of samples of arms and ammunition or weapons for the existing ammunition sample, the research of powders to determine their strength, speed and burning law and others.

The important component of the effective small arms usage is ensuring of definite nature of the bullet action at certain distances. The ballistic firing elements present the pressure changes of powder gases $P(t)$ and velocity $V(t)$ of a throwing element as a function of time of its motion in the barrel since the beginning of the first period of shot. The availability of these data has a high importance.

These relationships make it possible to determine the influence of separate charging terms on the nature of the powder gases impact on the muzzle brake, gas operated devices and other mechanisms, which use the energy of powder gases [1–4], to evaluate the condition of small arms and ammunition that are used, taken from the long-term storage, new or upgraded.

The information taken from the ballistic firing elements is used by designers while designing the barrel, locking component parts, while calculating of the kinematics and dynamics of moving parts, recoil energy, and while solving other problems that are related with the development or modernization of the armament and ammunition.

**Analysis of publications.** As the gradual improvement of small arms takes place, the requirements to the accuracy of ballistic firing elements determination is increasing. For example, the permissible value of the relative error of the pressure law determining is about several percents [1; 2], that is required for the adjusted calculation of the barrel construction, weapons parts and mechanisms, and for the diagnostics of the ammunition condition after long-term storage.

More rigid requirements are demanded on the accuracy of ballistic firing elements determination for the kinetic non-lethal weapons [5]. This is due to usage of such a weapons only in the narrow range of distances to the target, so that the given impact of the throwing element on the target should be provided (e.g., to avoid the physical destruction of the object while providing the loss of his ability to the getaway, offence or resistance).

The characteristics of the ballistics firing elements, obtained theoretically, may differ significantly from the characteristics of real processes, because the decisions are based on numerous assumptions and simplifications. For example, the value of the maximum pressure of powder gases founded by analytical and empirical methods using the ballistic tables [1; 6] may differ from the experimentally obtained value from 2 to 10 % (depending on the relative weight of the projectile and the values of some coefficients).

One of the perspective ways to improve the accuracy of the ballistic firing elements definition is the implementation of their experimental reception by measuring of instantaneous values of relevant parameters. The experimental curves for ballistic firing elements allow to apply well-known and well-developed theoretical methods of internal ballistics, but also may become the basis for further refinement of the decisions obtained theoretically [1–4].

The well-known methods and means of the barrel powder gases pressure measuring while firing are based on pressure sensor plunging into the barrel [7; 8]. However, a significant drawback of this approach is the irreversible destruction of the arms sample. Thus, the justification of ways of experimental determination of ballistic firing elements at the required accuracy provided and at the condition of non-destructive testing of the arms sample is an actual scientific problem.

**The aim of the article** is to perform the analysis and the justification of prospective methods and means of the experimental determination of ballistic firing elements.

**Statement of the main content.** Using the equation of the gradual movement of the throwing element in the barrel [3], we can see that

$$P(t) = \frac{\varphi m}{s}\frac{\mathrm{d}V(t)}{\mathrm{d}t} = \frac{\varphi m}{s}a(t)\,, \tag{1}$$

where$s$ – cross-sectional area of the bore; $a(t)$ – acceleration of the throwing element; $m$ – mass of the throwing element; φ – coefficient of the fictitiousness, that considers the loss of powder gases energy due to minor works while the throwing element is moving in the bore.

Secondary works are expended on the rotational motion of the projectile, on the frictional force between the leading part of the projectile and the surface of the bore overcoming, on the gas charge and powder grains that are not burned movement, on the work of the mechanisms and the parts of the automatic weapon movement, on the leading bands of the projectile or leading part of the bullet cutting in grooves, on the barrel, the projectile and the shell heating, on energy loss due to breakthrough of powder gases between the projectile and the barrel side, on the air resistance overcoming and the displacement of the air from the bore [3]. The other secondary works are neglected.

As it can be seen, there is a definite relationship between the ballistic firing elements $P(t)$ and $V(t)$. So it's possible to determine the relation $P(t)$ based on the data of $V(t)$.

It is necessary to get the array $V_i, i = \overline{1,n}$ of instantaneous values of velocity by measuring them with a sampling interval $\Delta t$ to solve this problem. Further definitions of $P(t)$ can be implemented by two ways:

– the polynomial approximation of the curve $V(t)$ according to the array $V_i, i = \overline{1,n}$, differentiation of the resulting polynomial by time (i.e. finding the analytical definition of the acceleration curve $a(t) = \partial V(t) / \partial t$) and calculation of $P_i$ values at any given time $t_i = i \cdot \Delta t$ by the expression (1);

– the direct calculation of instantaneous values of $a_i$ of the acceleration

$$a_i = \frac{V_{i+1} - V_i}{\Delta t} \tag{2}$$

by the instantaneous values of velocity $V_{i+1}, V_i$ for two adjoining points of the array $V_i, i = \overline{1,n}$ and calculation of the $P_i$ values at a given time by the expression

$$P_i = \frac{\varphi m}{s}a_i\,. \tag{3}$$

Thus, the measuring of the instantaneous values of the in-bore throwing element velocity is the perspective way of clarification of the ballistic firing elements.

The common methods and means of the bullet speed measuring (i.e. chronograph, optical and inductive measuring devices, etc.) provide measurements only outside of the bore and aren't adapted for the first and the second periods of the shot [8]. Therefore, the development of the theoretical and applied bases of in-bore velocity of the throwing element measuring is the actual scientific problem.

The optical differential Doppler's method may be used as the basis of the measuring instrument for the in-bore velocity of the throwing element measurement. This method is based on the allocation and registration of Doppler's frequency shift between two coherent laser light waves that are directed to the throwing element at different small angles to the longitudinal axis of the bore. The reflected radiation contains two waves, that (due to the effect of interference) create the signal, which carries the information about the velocity of the throwing element [9; 10]. The continuous registration of the difference frequency for the time while the first and the second periods of the shot last will allow to receive the arrays $V_i, i = \overline{1,n}$ of the instantaneous velocity values for their further processing to calculate the instantaneous pressure values.

In accordance with the preliminary estimates such measuring instrument is characterized by the high potential attainable accuracy of instantaneous velocity values determination of and, at the same time, by the desired operation speed.

However, the creation of Doppler in-bore velocity measuring instrument is a difficult scientific and engineering problem. The specificity of perception, transmission and processing of the measuring information is conditioned by high top limit of speed measuring range (up to several hundreds of m/s), by small duration of the shot (up to 0,001 s) and by extreme values of impact values (for example, mechanical vibrations of the weapon during firing) [3].

The development of design and application principles of the Doppler velocity measuring instrument may be possible as a result of solving of a number of scientific problems solving, the main of which should be determined as follows.

1. Analysis of the peculiarities of the throwing elements in-bore velocity measuring. Research of the of measurement conditions, impact values, the development of requirements to the basic technical characteristics of velocity measuring instrument. Selection and justification of the principle of construction of the optical scheme of Doppler in-bore velocity measuring instrument.
2. Construction of the generalized mathematical model of velocity measuring instrument, obtaining of the calibration characteristic, analysis of its metrological characteristics. Establishing of the relationships between the parameters of the mathematical model and the physical parameters of velocity measuring instrument, development of methods of synthesis of the measuring instrument with desired characteristics.
3. Justification of the requirements to the composition and elements characteristics of the structural scheme of Doppler velocity measuring instrument. Development of a generalized algorithm of processing of measuring information considering the requirements to accuracy of determination of curves of speed and pressure. Justification of recommendations for hardware and software for this algorithm.
4. Construction of mathematical models, analysis of character and values of the measurement error components. Development of ways of desired accuracy of measurement ensuring. Evaluation of the resulting instrumental error, justification of recommendations for implementation and use of measuring instrument.
5. Experimental verification of the adequacy of mathematical models of velocity measuring instrument elements and of models of measuring information processing procedures.

The modern in-bore throwing element velocity measuring instrument should be created on the bases of investigation results, which should be made within the specified destinations. This will allow to obtain experimentally the reliable measuring information about the ballistic firing elements provided that the growing requirements to the accuracy are met.

## Conclusion

It is necessary to have specified information about ballistic firing elements in order to solve the problems of designing and upgrading of weapons, justification of barrel design, parts and mechanisms design, and optimization of automatics. It is possible to increase the reliability of modeling of the internal ballistic processes by means of specification of solutions obtained theoretically and based on the results of measuring experiment.

The implementation of experimental determination of ballistic firing elements based on the creation of measuring instrument for in-bore throwing element velocity measurement will allow:

– to increase the reliability of diagnostics and operational control of technical condition of weapon and, as a result, to reduce the probability of using of the faulty weapons;

– to establish the dependence between the pressure of powder gases and the velocity of throwing element in different sections of the bore in the function of path (time) and, thus, to increase the accuracy of solving of the direct problem of internal ballistics;

– to predict the technical condition of some samples of the main types of weapons on the basis of the research of their characteristics drift in time and in working hours;

– to obtain the clarified original data about the nature of the internal ballistic processes in order to design, upgrade and improve the construction of the main types of weapons;

– to provide the possibility of investigation and optimization of the characteristics of the prototypes of weapons during their tests.

## References

1. Голомбовский, А. К. Теория и расчет автоматического оружия [Текст] / А. К. Голомбовский. – Пенза : ПВАИУ, 1973. – 492 с.

2. Кириллов, В. М. Основы устройства и проектирования стрелкового оружия [Текст] / В. М. Кириллов и др. – Пенза : ПВАИУ, 1963. – 342 с.

3. Серебряков, М. Е. Внутренняя баллистика [Текст] / М. Е. Серебряков. – М. : Оборониздат ГИОП, 1949. – 469 с.

4. Анипко, А. Б. Внутренняя баллистика ствольных систем при применении боеприпасов длительных сроков хранения [Текст] : монография / О. Б. Анипко, Ю. М. Бусяк. – Х. : Акад. ВВ МВД Украины, 2010. – 128 с.

5. Наказ про затвердження "Інструкції про порядок виготовлення, придбання, зберігання, обліку, перевезення та використання вогнепальної, пневматичної і холодної зброї, пристроїв вітчизняного виробництва для відстрілу патронів, споряджених гумовими чи аналогічними за своїми властивостями метальними снарядами несмертельної дії, та зазначених патронів, а також боєприпасів до зброї та вибухових матеріалів" від 16.03.2012 № 207 [Копія] / МВС України. – К.

6. Ермолова, С. И. Таблицы внутренней баллистики [Текст] / С. И. Ермолова, В. Е. Слухоцкий. – ч. 1. – М. : Воениздат, 1948. – 448 с.

7. Медведева, Н. П. Экспериментальная баллистика [Текст] : учеб. пособие / Н. П. Медведева. – Томск : Томский ун-т, 2006. – ч. 1. : Методы измерения давления. – 172 с.

8. Шкворников, П. Н. Экспериментальная баллистика. Приборы и методы баллистических измерений [Текст] / П. Н. Шкворников, Н. М. Платонов. – М. : Оборонгиз, 1953. – 392 с.

9. Ринкевичюс, Б. С. Лазерная анемометрия [Текст] / Б. С. Ринкевичюс. – М. : Энергия, 1976. – 159 с.

10. Ринкевичюс, Б. С. Методы лазерной доплеровской анемометрии [Текст] / Б. С. Ринкевичюс, Ю. Н. Дубнищев. – М. : Наука, 1982. – 304 с.

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